Switchable eight-wavelength laser based on broadband chirped fiber grating and 50 μm MMF

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A novel erbium-doped fiber laser outputting simultaneously eight-wavelength at most was presented. This laser employed the simple structure of linear cavity. Two Sagnac loops constituted two cavity mirrors of the laser. A broadband chirped fiber grating (BCFG) with 3dB linewidths of 40 nm, a three-ring-type polarization controller (PC) and a 3dB fiber coupler (FC) consisted of left Sagnac loop. The BCFG also had the optical signal-to-noise ratio (OSNR) of 18 dB. Right Sagnac loop consisted of another same FC and a length of 3 m long multimode fibers (MMFs) with core diameter of 50 μm. The two loops based on different operational principles became two different comb filters, which could mutually produce the multiple wavelengths to output. When the PC was rotated continually to different locations and would cause the PHB effect, the laser could flexibly switch to export sixteen sorts of different lasing lines. The whole lasing lines had less than 0.23 nm linewidths and the OSNR of greater than 17 dB. The laser showed better power and wavelength stabilities at room temperature.

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Keywords: Erbium-doped fiber laser, Broadband chirped fiber grating, Comb filter

1. Introduction

In the past decades, multi-wavelength fiber lasers received increased attention because they played a crucial role in fiber sensors, DWDM optical communications and so on. In order to obtain stable multi-wavelength output, different combination schemes using chirped fiber gratings (CFGs) as the main component of wavelength selection were reported. For example, CFG and polarization-maintaining fiber [1], CFG and high-order mode-locking [2], CFG and a switch module [3], CFGs and a semiconductor optical amplifier [4]. Other schemes using multimode fiber (MMF) was also reported, such as MMF and triple-core photonic crystal fiber [5], MMF and passive Q-switching [6], MMFs with different core diameters [7], MMF and mode-locked technology [8].

For these references, there are some shortcomings, for instance, less maximum wavelength number, less amounts of lasing lines, larger insertion loss caused by non-optical fiber equipment, poor homogeneity. An eight-wavelength erbium-doped fiber laser (EW-EDFL) reported by this letter can well overcome the above shortcomings and makes great improvement. It used the structure of linear cavity. A broadband CFG (BCFG) in the left loop and a length of 3 m long MMFs in the right loop were employed to mutually produce multi-wavelength. This laser could output sixteen sorts of diverse lasing lines.

2. Experiment

The structural sketch of the EW-EDFL is displayed in the Fig. 1. It employed the structure of linear cavity which consisted of left and right Sagnac loops. A novel BCFG, a three-ring-type polarization controller (PC) and a 3 dB fiber coupler (FC) were welded together in order and formed the left loop. A length of 3 m long MMFs with 50 μm core diameters and another same 3 dB FC were welded together in order and formed the right loop.

A 980 nm laser diode (LD) was used as pump source of the laser. By wavelength division multiplexing (WDM) coupler, 980 nm pump light entered the laser cavity to excite 5 m EDFs, which were made by Fibercore Limited Company.

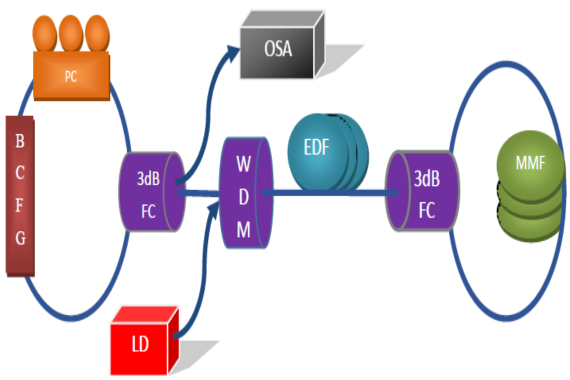

Fig. 1. Structural sketch of the EW-EDFL (color online)

3. Results and discussion

In the Fig. 2, the upper picture shows experimental setup of fabricating the BCFG. A light path system was built by us. By it, a UV laser was used to shine the phase mask (in the middle picture) and then exposed the fiber to form the grating. Reflection spectrum of the novel BCFG is shown in the lower picture. This grating has 3dB linewidths of 40 nm and the optical signal-to-noise ratio (OSNR) of 18 dB. It has 90% reflectivity and the chirp rate of 7 nm cm^{-1}.

According to the work principle of CFG in the Ref. [9], when a fiber grating is welded in Sagnac loop, this loop can form a comb filter. Many bandpasses (i.e. multi-wavelength) are generated in the reflection spectrum of this grating. If the range of reflection spectrum is expanded, more bandpasses will produce. The length difference (ΔL) of two arms of the 3-dB FC in the left loop is 3 meters, which indicates the channel spacing of the left comb filter is extremely small (~ 2.7×10^{-4} nm). Thus, the channel spacing is mainly dependent on the right loop (with MMF).

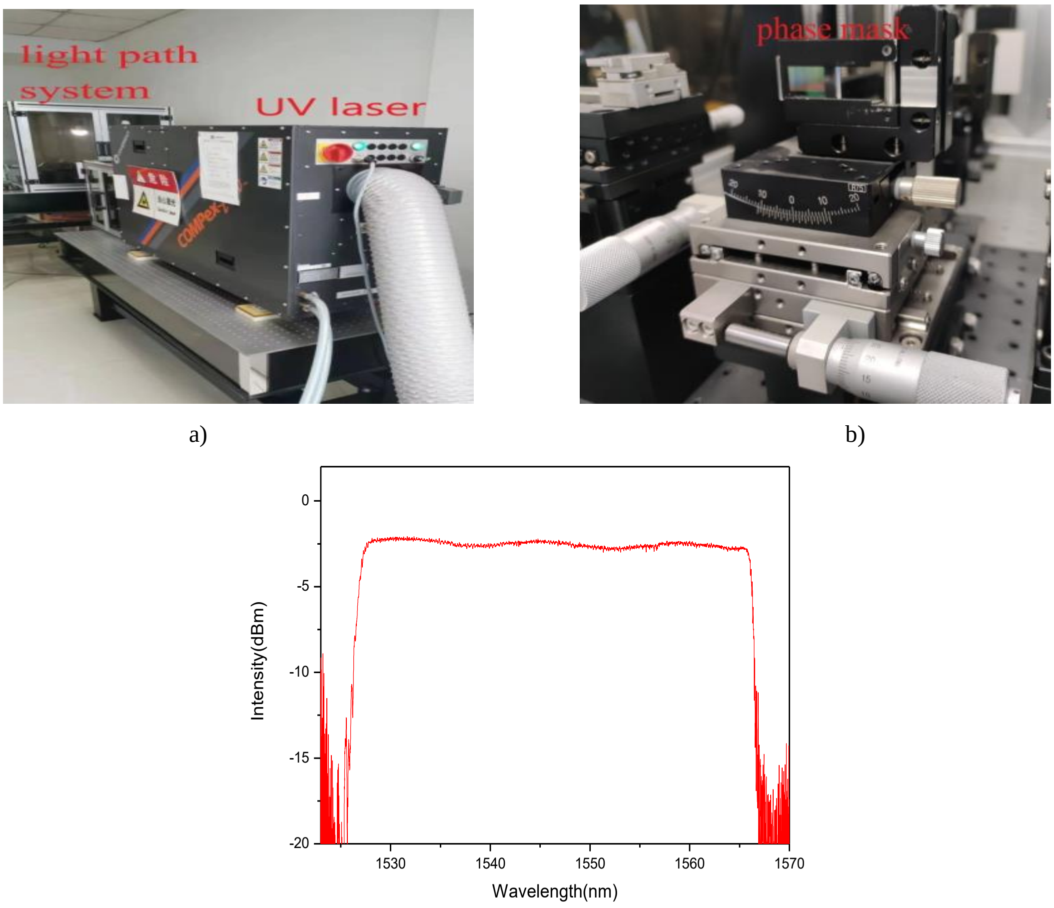

Fig. 2. Experimental setup of fabricating the BCFG (a), phase mask (b) and reflection spectrum of the BCFG (c)

Meanwhile, according to multimode interference theory, the separation of neighboring transmission peaks in the multimode interference effect can be expressed for [10]

$$\Delta\lambda = \frac{n_{MMF} D_{MMF}^2}{L} = \frac{1.45\times2500\times10^{-12}}{3} = 1.2\text{nm}$$

where n_{MMF}, D_{MMF}, L are refractive index, the diameter of fiber core, the length of MMF. So when n_{MMF}, L are fixed, the peak separation $\Delta\lambda$ will become denser by decreasing the diameter of fiber core D_{MMF}. This contributes to produce more lasing lines. Thus 50 μm diameters are better than 62.5 μm diameters for fiber core of MMF. So we used 50 μm MMF in the experiment.

When the power of LD was fixed at 300 mW in the experiment, an AQ6375B optical spectrum analyzer (OSA) measured the laser outputting from the left loop. This OSA has 0.02 nm minimum resolution.

Adjusting the PC made propagating lights change their polarization states. Losses related with polarization would be produced. The polarization hole burning (PHB) effect would appear. When the loss of one wavelength is more than its gain, it will disappear. On the contrary, a new wavelength will appear. The locations of lasing lines would happen to change at random. Finally, under the cooperation of the BCFG and MMF, 16 kinds of diverse lasing lines were achieved. These lasing lines were displayed in Figs. 3, 6-10. Meanwhile, the fluctuations of their wavelength and peak power were measured.

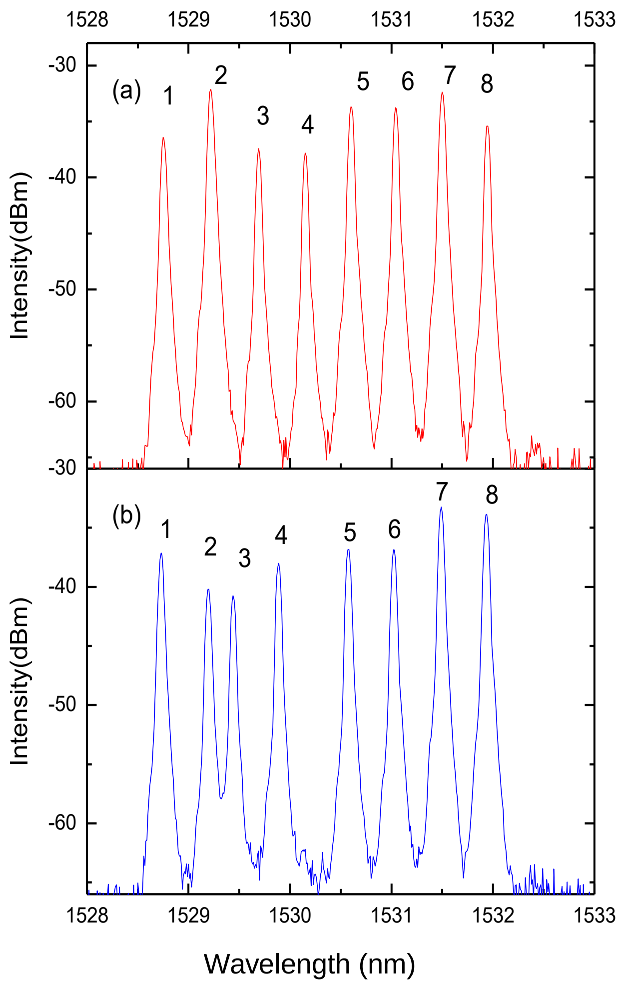

Fig. 3. Two sorts of eight-wavelength spectra (color online)

Table 1. Eight-wavelength parameters

Figure	MPPD (dB)	3 dB linewidth (nm)	OSNR (dB)	Center wavelength of peaks (nm)
3(a)	≤6	≤ 0.23	≥ 27	1528.73,1529.21,1529.69,1530.15, 1530.60, 1531.06, 1531.51, 1531.96
3(b)	≤ 8	≤ 0.18	≥ 24	1528.73,1529.21,1529.44,1529.90, 1530.57, 1531.03 ,1531.48,1531.95

After the PC was slowly adjusted, the laser could emit two sorts of eight-wavelength lasing lines (a) and (b) as shown in the Fig. 3. Their optical parameters including maximum peak-power difference (MPPD), OSNR, 3 dB linewidth, center wavelength of peaks are displayed in the Table 1. In order to test their stabilities, eight-wavelength (a) was further measured. Fig. 4 displayed its 4-times repetition sweep spectra. It could be seen that eight lasing lines have no obvious wavelength deviations.

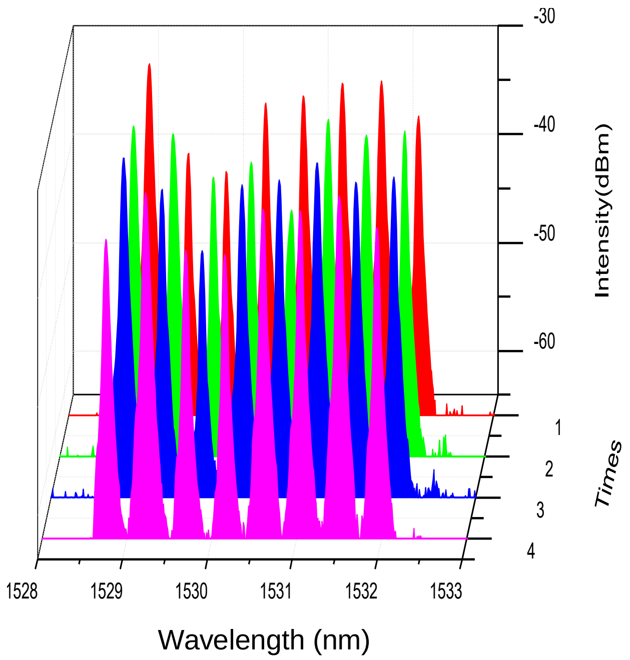

Fig. 4. 4-times repetition sweep spectra for the eight-wavelength (a) (color online)

Fig. 5 displayed power fluctuations of eight peaks in the eight-wavelength (a) across time. The maximum and minimum peak-power differences of the 1530.60 nm and 1531.06 nm lasing lines during the 60 minutes are 8 dB and 0.8 dB.

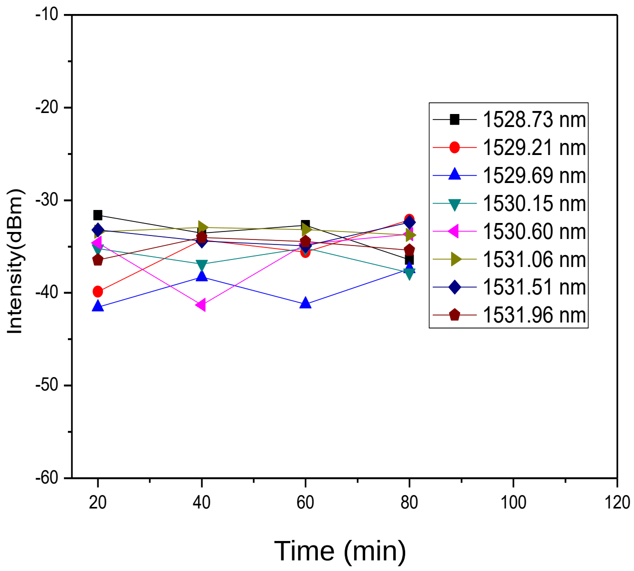

Fig. 5. Power fluctuations of eight peaks across time (color online)

The PC was kept on turning, it could output two sorts of seven-wavelength lasing lines (c) and (d) as displayed in the Fig. 6. Their parameters are shown in the Table 2.

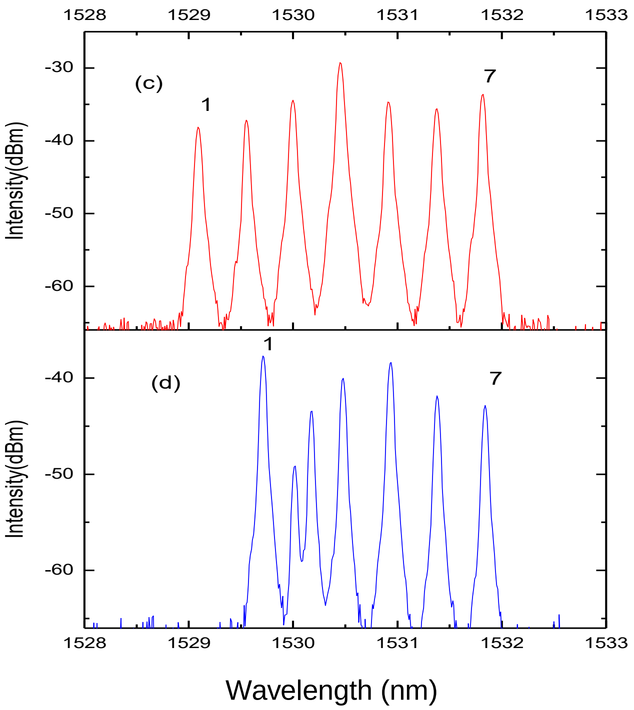

Fig. 6. Two sorts of seven-wavelength spectra (color online)

Table 2. The parameters of seven-wavelength

Figure	MPPD (dB)	3 dB linewidth (nm)	OSNR (dB)	Center wavelength of peaks (nm)
6(c)	≤ 9	≤ 0.18	≥ 27	1529.08,1529.54,1529.98,1530.45, 1530.89, 1531.38, 1531.80
6(d)	≤ 12	≤ 0.12	≥ 17	1529.73,1530.01,1530.16,1530.48, 1530.94, 1531.38, 1531.85

Furthermore, the laser could emit five sorts of six-wavelength lasing lines (e)-(i) as displayed in the Fig. 7. Table 3 shows the whole six-wavelength parameters.

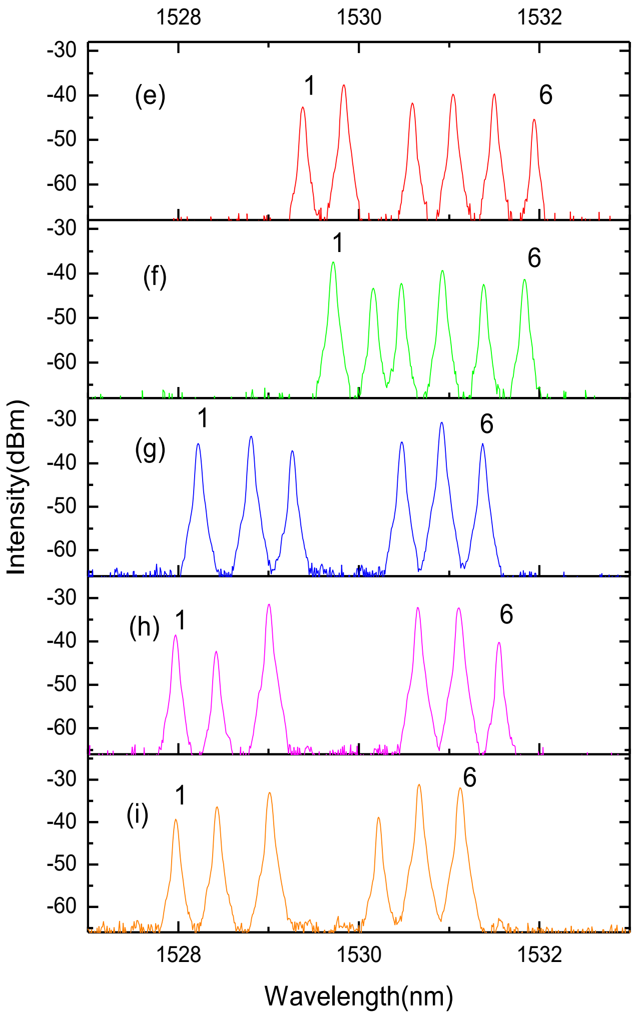

Fig. 7. Six-wavelength spectra (color online)

Table 3. The parameters of six-wavelength

Figure	MPPD (dB)	3 dB linewidth (nm)	OSNR (dB)	Center wavelength of peaks (nm)
7(e)	≤7	≤ 0.16	≥ 23	1529.38, 1529.82,1530.59,1531.03,1531.50, 1531.93
7(f)	≤ 5	≤0.19	≥23	1529.72,1530.13,1530.47,1530.94, 1531.36, 1531.81
7(g)	≤6	≤0.18	≥ 28	1528.23,1528.83,1529.29,1530.48,1530.94, 1531.37
7(h)	≤10	≤0.22	≥24	1527.98,1528.41,1529.01,1530.66,1531.09, 1531.56
7(i)	≤8	≤ 0.18	≥ 25	1527.99,1528.45,1529.00,1530.22,1530.69, 1531.12

The laser can output three kinds of three-wavelength lasing lines (j),(k),(l) as shown in the Fig. 8. The whole three-wavelength parameters are displayed in the Table 4.

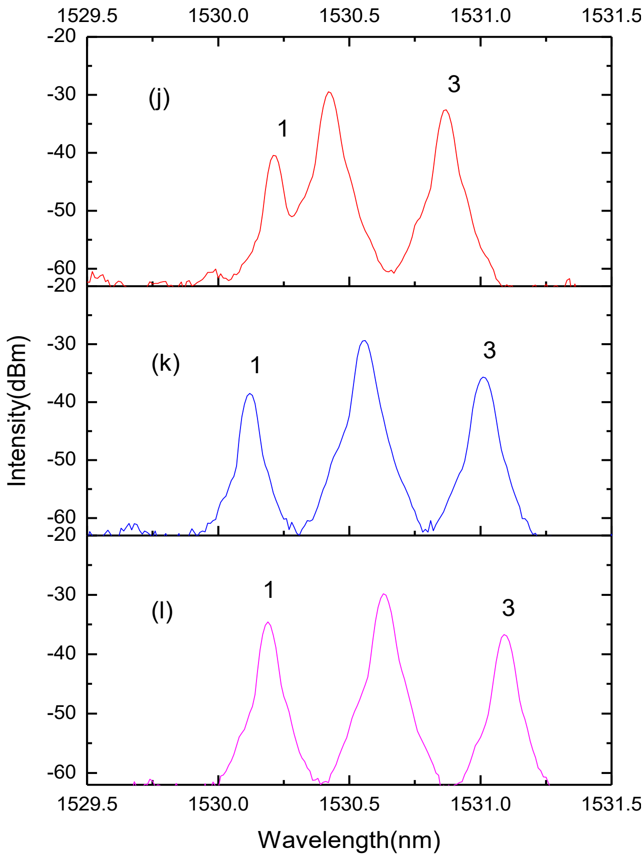

Fig. 8. Three-wavelength spectra (color online)

Table 4. The parameters of three-wavelength

Figure	MPPD (dB)	3 dB linewidth (nm)	OSNR (dB)	Center wavelength of peaks (nm)
8(j)	≤11	≤0.19	≥ 21	1530.21,1530.43,1530.87
8(k)	≤ 10	≤0.18	≥ 22	1530.13, 1530.54,1531.03
8(l)	≤ 7	≤ 0.19	≥24	1530.19,1530.62,1531.09

The laser can emit two kinds of dual-wavelength lasing lines (m), (n) as shown in the Fig. 9. The whole dual-wavelength parameters are displayed in the Table 5.

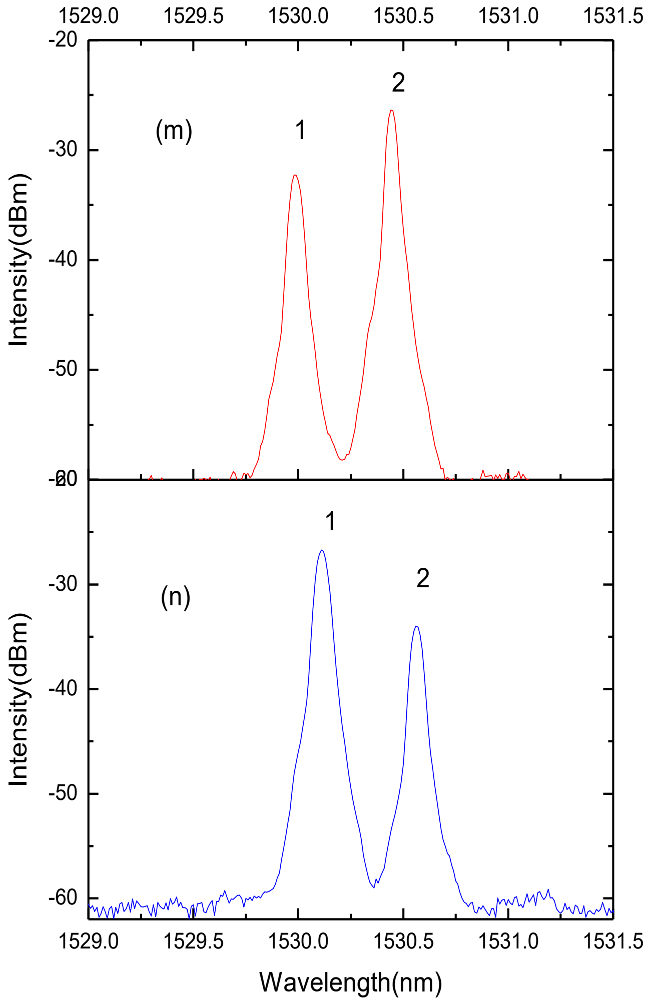

Fig. 9. Dual-wavelength spectra (color online)

Table 5. The parameters of dual-wavelength

Figure	MPPD (dB)	3 dB linewidth (nm)	OSNR (dB)	Center wavelength of peaks (nm)
9(m)	≤ 6	≤0.21	≥ 26	1529.99,1530.45
9(n)	≤7	≤ 0.21	≥ 27	1530.11, 1530.56

The laser can output two kinds of single-wavelength lasing lines (o), (p) as shown in the Fig. 10. The whole single-wavelength parameters are displayed in the Table 6.

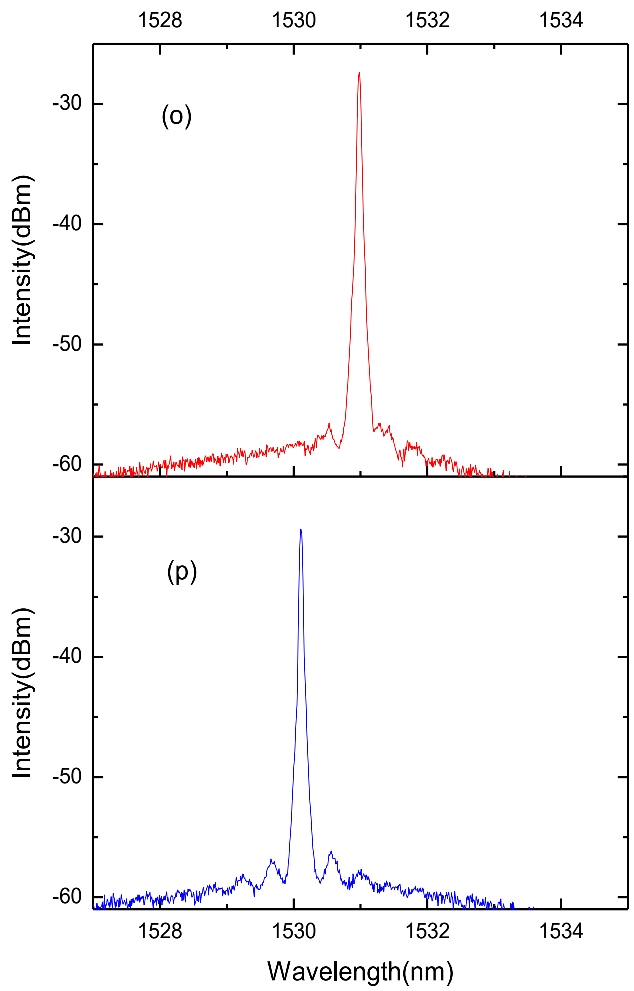

Fig. 10. Single-wavelength spectra (color online)

Table 6. The parameters of single-wavelength

Figure	3 dB linewidth (nm)	OSNR (dB)	Center wavelength of peaks (nm)
10(o)	≤0.16	≥ 30	1530.95
10(p)	≤0.16	≥ 29	1530.08

4. Conclusion

A switchable EW-EDFL employing linear cavity structure was designed and experimentally proved. Its cavity mirrors consist of two Sagnac loops. Two loops are mainly composed of MMF and a BCFG, respectively. They form two different wavelength selectors to mutually produce multi-wavelength. When the PC is slowly turned, the laser can switch to output sixteen sorts of diverse lasing lines.

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